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AUTOMATED THEMATIC MAPPING AND CHANGE DETECTION OF ERTS-A IMAGES

Nicholas Gramenopoulos  
Optical Systems Division  
Itek Corporation  
10 Maguire Road  
Lexington, Massachusetts 02173

December 1972

Interim Report for Period June - November 1972

Prepared for  
GODDARD SPACE FLIGHT CENTER  
Greenbelt, Maryland 20771

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## SUMMARY

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Author: Nicholas Gramenopoulos

## ABSTRACT

For the exploitation of the ERTS-1 images, both multispectral and spatial pattern recognition techniques are important. A multispectral recognition software program was successfully tested. A technique for the generation of resource boundaries has been successfully combined with terrain recognition software resulting in a regionalized terrain classification system. Digital registration of multispectral images has been achieved.

Also, photointerpretation results from one test site are reported and the development of spatial terrain signatures from optical diffraction patterns is described.

## PREFACE

### a. Objective

The objective of the investigation is to develop digital interpretation techniques such that earth resources and their changes with time can be recognized automatically from ERTS-1 images. Such techniques are expected to increase the utility of the large volume of imagery produced by the satellite by providing for efficient processing of the data.

### b. Scope of Work

Under the investigation, multi-spectral and spatial pattern recognition techniques are being developed so that both the multi-spectral and spatial pattern information in the ERTS-1 images can be exploited. Interpretation results from both methods will be merged to expand the number of resources that can be recognized and increase the accuracy of recognition.

ERTS images from six test sites will be subjected to the interpretation process to provide a variety of resources for testing the techniques.

### c. Conclusions

The research activities during the period covered by the report indicate that the objective of the investigation can be met. Spatial signatures can be used to recognize terrain types; boundaries enclosing resource classes can be generated and multi-spectral programs can recognize a different group of resources. Furthermore, through digital image registration, it is possible to digitally determine changes in resources with time.

### d. Recommendations

The digital processing is complex and best results are achieved when the investigator can visually monitor the outputs of the processing operations. Therefore, it is recommended that man-computer interaction be increased through computer driven visual displays.

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## 1. INTRODUCTION

This is the Type II report required by the contract for the period of June 15 - November 15, 1972. The purpose of the report is to describe the technical progress of the project for this period.

The main body of the report is divided into the following sections:

A. Input Data Operations, which describes the data that has been received from NASA, the data handling operations necessary for the utilization of the data, and the data required to complete the project.

B. Photointerpretation Tasks complete and in progress. These tasks are necessary for the location of ground truth, familiarization with the test sites and the ERTS images and for evaluating the digital processing operations.

C. Digital Interpretation Techniques. This section describes development of software packages that are essential to the digital processing of ERTS images. This section includes a multi-spectral detection program which recognizes resources by their reflectances in the ERTS spectral bands, a program that develops boundaries enclosing areas occupied by resources of the same classification, and a program which registers digital images of the same or different spectral bands. This program is essential for performing change detection between ERTS images of a specific area obtained at different times.

D. Development of Terrain Spatial Signatures. This section describes a task for developing spatial signatures for various types of terrain. These can then be used with our spatial detection program to recognize terrain types. The signatures are developed optically from the diffraction patterns of small areas of the ERTS images and their detection is then implemented digitally.

E. Conclusions. This section describes the conclusions that can be drawn from the work performed.

F. Program for Next Reporting Interval. The work planned for the remaining time interval of the investigation is presented in this section.

G. Recommendations.

The intent of this report is to provide a clear understanding of the work performed. However, significant results and technical details from the above tasks will be reported in separate reports.

## 2. INPUT DATA OPERATIONS

### 2.1 ERTS Images

Since the delivery of the first ERTS image on September 12, 1972, a substantial number of 9-1/2 inch positive images has been delivered to the project fulfilling one of the goals of the ERTS program for repetitive complete coverage of the continental United States and many other parts of the world. Most of the images arrived during October and November 1972. A system of checking and cataloging these images has been developed so that they can be utilized by the project efficiently.

Through the standing orders, the project receives black and white positive transparencies on 9-1/2 inch film. These arrive now about one month after acquisition. The images may contain a portion or an entire test site, and are the first indication that a test site has been acquired on a specific date. The standard catalogs arrive later and the microfilm catalog, which is very useful, is further delayed. Upon receipt of the transparencies, an overlay is produced photographically. The overlay contains all the annotations and coordinate marks of the MSS 5 (Red Band) image. Geographic coordinates and the test site coordinates are plotted on the overlay. Using the overlay, it is possible to determine the percentage coverage of the test site. At this point, a decision is made whether to submit a request for digital tapes. The decision is based on cloud cover, haze, percentage of test site photographed, as well as on previous acquisitions of the test site. The satellite produces a lot of images so that a selection is possible.

The ERTS images are also being utilized for the photointerpretation tasks (section 3) and for the development of terrain spatial signatures (section 5). Both of these operations require changes in scale which are accomplished very efficiently photographically. The photointerpretation tasks require enlargements while the spatial signatures require high resolutions reductions in scale in order to obtain large diffraction patterns.

### 2.2 ERTS Digital Tapes

The first digital tapes were delivered on October 30, 1972, and were 9-track. Existing digital tape recorders in Itek's Computation Center can handle 7-track 556 BPI tapes, so the 9-track tapes could not be used without converting them to 7-track 556 BPI tapes. The conversion could be done by an independent computer center. However, the project would have had to absorb the costs of the conversion, additional tapes and the labor associated with the handling required by the conversion. It was decided not to burden the project with the cost of an unnecessary data handling operation and the 9-track tapes were returned to NDPF. The project technical monitor, Mr. Edmund F. Szajna, was notified of the situation and acted promptly to correct it. In the first two weeks of November, a number of tapes were delivered which were 7-track, 800 BPI. These could not be used also and were returned. Finally, in the end of November, several 7-track, 556 BPI tapes were delivered and the project is utilizing them in several digital processing operations.

### 2.3 Aircraft Images

Low altitude photography (10,000 feet) from all six test sites has been delivered by NASA-MSC. High altitude photography (60,000 feet) from two test sites, Weslaco, Texas and New Orleans, Louisiana, has also been delivered. In general, the photography is very good and is being fully utilized by the photointerpretation tasks (section 3). It has been observed that the high altitude photography is very useful because of the larger area covered: 14 x 50 square nautical miles versus 2.8 x 50 square nautical miles for the low altitude photography. It is highly desirable to obtain high altitude photography either by a U-2 or RB57F aircraft over the remaining four test sites.

### 3. PHOTOINTERPRETATION TASKS

Photointerpretation of the ERTS and aircraft images from the six test sites is being conducted for two reasons:

1. Ground truth identified on a map must be located accurately in the ERTS images. The ground truth location is accomplished through the use of larger scale images of the same area from aircraft underflights. The technique had to be tried and refined for ERTS-A images.
2. A lot of detail is obvious in the ERTS images and most of it can be identified by comparison to maps and aircraft photography. The objects or structures that can be identified give clues as to the information that can be retrieved digitally from the ERTS images.

A photointerpretation task on the Weslaco, Texas test site (ERTS image 1038-16314) has been completed and another task on the Cascade Mountains test site is in progress. The conclusions drawn from the photointerpretation of the Weslaco area are:

1. The ERTS images have sufficient resolution for monitoring agricultural resources in crops larger than 40 acres. This conclusion basically agrees with Professor Colwell's findings for ERTS images of California.
2. Substantial cloud cover (about 50%) as is experienced during summer over Weslaco, greatly reduces the usefulness of a multi-spectral analysis of farms since most farms of 160 acres or larger are completely or partially covered by clouds or their shadows.
3. The IR2 band (0.8 - 1.1 micron) gives excellent results for the identification of surface water. Even small bodies of water (about 4 acres) were definitely identified and easily distinguished from cloud shadows. This band does not appear to give information about water depth or clarity, but defines rather precisely the boundaries between wet areas and dry land.
4. Most geographic features such as lagoons, lakes, islands, river beds, marshes, large canals, docks can be clearly identified in the ERTS images.

5. The ERTS images provide information for the analysis of river effluents, silting of harbors and the movement of water with the tides.
6. Urban areas are not well identified from spatial characteristics, but can be delineated from multi-spectral signatures.
7. Major highways can be identified, but smaller roads are not visible.
8. Haze appears to have reduced the contrast of the ERTS images even though the red, IR1 and IR2 bands are able to penetrate haze.
9. Very small bright objects such as gas tanks or buildings can be detected in the ERTS images and can be identified through the aid of accurate maps.
10. There is an apparent need to update existing maps (1:250,000 scale) of the area.
11. The red band (0.6 - 0.7 micron) has the most information. It carries some of the information available in the other three bands.
12. In the ERTS images, there is no evidence of variation in reflectance due to the look angle, while in the aircraft images, substantial variation due to look angle and specular reflection from bodies of water was readily apparent.

#### 4. DIGITAL INTERPRETATION TECHNIQUES

##### 4.1 Multi-Spectral Recognition Program

The multispectral recognition program identifies resources by their reflectances in several spectral bands. The algorithm assigns a picture element to one of a number of resource classes using the maximum likelihood ratio (see Reference 1). The number of classes and their covariance matrices are a priori determined.

The program consists of two parts; one for training operations and another for recognition operations. For training, one or more multi-spectral images of known classification can be inputted and the training program will compute the covariance matrices for the classes present in the data. Conversely, the covariance matrices can then be employed to assign new data to resource classes by the maximum likelihood ratio criterion which minimizes the probability of error. The technique has been the classical approach in pattern recognition and can be applied to many statistical recognition problems by replacing the spectral reflectance data with measurements of other physical quantities. The technique is limited to recognizing resource classes for which the covariance matrices are known (from training data). Also, the probability of error increases if the distribution of spectral data for a given class deviates significantly from the Gaussian multivariate distribution associated with the covariance matrix.

A number of errors had been noted in the multi-spectral recognition program and a number of tests were done with simulated MSS data to find the errors and check the operation of this program. Simulated data was used in order to be able to check closely the various program functions. The simulated images were generated from published (see Reference 2) reflectance

values of 16 different materials at specific wavelengths. Average reflectances for these materials over the MSS spectral bands were computed. Four spectral images (one for each spectral band) were developed for training purposes and four different images for recognition. Each image contained 1,024 x 1,024 pixels and it was divided into 16 squares (one for each class) of 256 x 256 pixels. Each pixel within a square was computed from a Gaussian random number generator such that the mean was equal to the average reflectance of the specific material in the particular spectral band. The standard deviation was selected randomly for each class and varied between 2% and 50% of the mean value. With a Gaussian number generator, some of the pixels came out negative and were replaced by zeroes. Also, due to the random number generator, all pixels were statistically independent of each other.

One set of spectral images was employed for training and the covariance matrices were computed by the program and checked manually for accuracy. The next set of spectral images was then used for testing the recognition algorithm, which employed the covariance matrices computed from the training operation. The program recognized correctly 94.5% of the pixels and rejected (did not classify) 0.8% of the pixels that had a zero value at one or more spectral bands. During the test, all errors in the program were found and corrected.

This program has not been tested with ERTS images due to the unavailability of 7-track, 556 BPI tapes. Such tapes are available now. A separate program to unpack the MSS bulk tapes has been written and successfully tested by retrieving the red MSS image and recording it on photographic film through our laser beam recorder. Under development is a program which determines the number of classes and their covariance matrices from an unknown set of data. This program will eliminate the need for training data or images.

#### 4.2 Edge and Boundary Detection Software

In the analysis of MSS multi-spectral images, it is important to identify the regions which have the same characteristics and to develop boundaries between adjacent regions. Theoretically, if each pixel is spectrally identified, then boundaries around image portions with the same characteristics can be developed. This approach has the drawbacks that the processing is inefficient in terms of computer time and normal errors in the multi-spectral detection create erroneous boundaries. In addition, no advantage is taken of any spatial information present in the images.

A new technique has been developed to perform automatic terrain classification based on edge detection of terrain regions characterized by spatial signatures. Boundaries of the regions are developed by derivative operations on digitized imagery. The derivatives alone do not lead to satisfactory boundaries. So, the boundary development starts with a low resolution version of the image (25X reduction), obtained by averaging groups of 25 x 25 pixels. This image is subjected to a derivative operator and a threshold to determine the location and direction of candidate edge elements. Topographic constraints are then imposed: the boundaries must be continuous and end on intersections. This operation eliminates isolated edge elements and fills the gaps in piecewise continuous boundaries. The end result is the partitioning of the image into regions.

This boundary map is then employed as a plan for the boundary map of the next higher resolution image, which is reduced only five times in relation to the original image. The 25X reduction boundary map is enlarged five times to fit the 5X reduction image. Then, the boundaries become at least 5 pixels wide. The boundaries of the intermediate image (5X reduction) are constrained to lie within the enlarged 25X reduction boundary plan. The intermediate image is subjected to a derivative operator and the resulting image is set to zero, except where it coincides with the enlarged boundary map. This operation defines the regions where the intermediate image boundaries are allowed to exist. In these regions, the intermediate derivative image is shrunk in width until it is only one pixel wide, the pixel being located on the derivative centroid. The shrinking operation guarantees boundary continuity and the boundaries are now only one pixel wide. An undesirable by-product of the operation is branches or appendages connected to the real boundaries. These are subjected to a topographic constraint and they are eliminated if they don't meet the constraint.

By a similar operation, the intermediate image boundary map is used as a plan for determining the boundaries of the high resolution original image. The end result is the partitioning of the image by the boundaries into regions.

The technique is elaborate, but avoids the pitfalls of simple derivative operations such as discontinuous, noisy, erroneous or multiple boundaries. One limitation is that an error in the 25X reduction boundary plan is propagated with no correction to the final boundary map. To correct errors in the first boundary plan, spatial terrain recognition has been employed in small regions of the original image selected by a rectangular grid. Changes in the terrain classification between adjacent regions indicates a boundary between them. No change indicates either no boundary or two boundaries. The results of the terrain classification are used to correct the boundary plans. Furthermore, the terrain enclosed by the boundaries can now be classified, and the boundary detection technique has evolved into an accurate regionalized terrain classification scheme. As such, the technique described has certain advantages:

1. Only 25% of the image is subjected to the spatial pattern recognition which is time-consuming.
2. Better classification results are achieved than if only spatial pattern recognition was applied to the entire image. For two specific images, the detection rates for cultivated land increased to 93.6% and 96.6% from 91.0% and 87%, respectively.
3. The classified regions are accurately delineated.

#### 4.3 Digital Image Registration

In order to digitally compare images acquired on different dates, of different spectral bands or different sensors, it is important to register them digitally. The project is employing MSS system corrected (bulk) spectral images. The MSS spectral images of a given area acquired on a given date by the satellite form a set which is inherently registered. However, images from different dates are not registered. In this case, to perform change detection one must register at least two spectral images from two different dates. This can best be done by registering the two red band MSS images to each other.

The registration technique depends on correlation of the two images. To reduce the required computer processing time, only a number (10-20) of small (64 x 64 pixels) areas are correlated. The shift in the correlation peak between two associated areas indicates the direction and magnitude of the shifting required to bring the two areas in registration. The areas that are correlated form the control points which provide samples of the relative distortion and displacement of the two images. To bring the two images in registration, every pixel is shifted by an amount which is a linear interpolation of the required shifts for the nearest control points. By drawing imaginary lines between control points, the images can be divided into triangular non-overlapping regions. A pixel located within one triangular region is subjected to x-y shifts which are linear interpolations of the required shifts for the three control points located at the apices of the triangle. This method works well and insures continuity in the shifted images.

The accuracy in the image registration is affected by errors in the correlations of the control points and to the extent that the relative image distortion deviates from the linear interpolation. The second type of error is easily corrected by increasing slightly the number of control points. However, errors in the correlations of the control points are the most troublesome. These arise from several sources:

1. Changes in the image such as cloud cover, or seasonal changes. This problem is avoided by selecting the control points manually and by correlating the image derivatives rather than the images directly.
2. Since the areas around the control points which are used for correlation are limited in size (64 x 64 pixels) the correlation may produce wrong answers when the displacement of two associated areas is a substantial portion of the area size. It has been observed that for good correlation accuracy, the image detail between two areas being correlated should overlap by at least 80%. Stated another way, the actual displacement between two areas correlated should be less than 20% of the area size. This effect has been known as the correlation pull-in range and has also been observed in electronic image correlators.

The problem of the limited pull-in range has been solved by a three step correlation technique. In the first step, the images are approximately registered manually. In the second step, the areas to be correlated around the control points are 320 x 320 pixels and are reduced (5X) by averaging to 64 x 64 pixels. The reduced control point areas are correlated and the original size images are shifted by linear interpolation. After this step, the images are coarsely registered within 10 pixels. In the final step, the control point areas are again 64 x 64 pixels, but in the original image resolution (no 5X reduction). The correlations of the control points are carried out again and the images are shifted by linear interpolation. After this step the images are registered within two pixels.

As mentioned earlier, two control areas are correlated after they have been subjected to a derivative operation, and all negative values have been inverted (made positive). The derivative operator is conveniently applied as a Fourier plane filter. For example, the Laplacian operator is equivalent to

multiplying the Fourier transform of the image by the function  $(w_x^2 + w_y^2)$  where  $w_x$  and  $w_y$  are the frequency variables in the x and y directions. We have tried both the gradient and Laplacian operators on two Apollo 9 photographic images (ERTS digital tapes were not available until recently) of the Salton Sea - Imperial Valley area. The images were the red band and the IR band, and the IR image was successfully registered to the red band. The Laplacian operator gave correlation functions with sharper peaks.

## 5. DEVELOPMENT OF TERRAIN SPATIAL SIGNATURES

The multi-spectral recognition techniques, described in section 4.1, ignore the spatial information in an image. Yet, the information conveyed to a human observer by a black and white image is purely spatial. The automated classification of resources can be significantly improved and expanded by utilizing the spatial information in the images. Terrain types can be digitally recognized if they can be associated with spatial signatures which can be defined as unique patterns in a set of measurements involving a small area of an image. The area size is bounded on the low end by the image resolution and on the high end by image characteristics. In other words, the average area analyzed should be significantly larger than image resolution (at least 10 x 10 pixels) and should not be so large as to include more than one type of terrain. Of course, the second condition cannot be met for every conceivable area in the image because an area selected around the boundary of two terrain types will by necessity display both types of terrain (such as a lake-cultivated land boundary). Fortunately, as discussed in section 4.2, it is possible to recognize the terrain types of an image by subjecting only 25% of the image area to spatial terrain signature analysis and the areas tested are selected so they don't contain boundaries. The area sizes that we conveniently use are 32 x 32 and 64 x 64 pixels.

The measurements that may be made and the technique for extracting a spatial signature are not restricted. The Fourier transform of an image is a convenient means to isolate and extract spatial signatures. The reason is that repetitive image characteristics are transformed into discrete frequencies which can be easier isolated.

The spatial signatures that can be isolated are dependent on image characteristics such as resolution and scale. For the ERTS images, spatial signatures are determined by examining the Fourier transforms from both ERTS and aircraft images for the same geographical area. The aircraft images being of higher resolution are useful for identifying spatial signatures which are very weak in the Fourier transforms of the ERTS images (such as urban areas). The most efficient way to establish terrain signatures for the ERTS images is optically, using the Fourier transforming properties of lenses. We are employing a special optical bench for this purpose which permits photographing the diffraction patterns and the images simultaneously. The bench also allows photometric measurements of any part (rings or wedges) of the diffraction patterns.

The relationship between Fourier transforms and diffraction patterns is not exact, the diffraction pattern being the amplitude squared of the Fourier transform of the square root of the image. If the image is photographically developed to a gamma of two, then the diffraction pattern is the amplitude squared of the Fourier transform of the image.

To obtain good size diffraction patterns, a long focal length lens (48 inches long) is being used. The diffraction patterns have some artifacts not related to the terrain images. These are:

1. Rings which are due to the circular aperture employed to limit the image area being transformed. These rings are also present in a digitally computed Fourier transform.
2. Two frequency spots due to the line structure present in the ERTS images. The line structure is a characteristic of the multi-spectral scanner and electron beam recorder system.
3. Artifacts due to the optical bench such as lens aberrations, laser beam non-uniformity, and phase modulation by the transparencies, since a liquid gate containing refractive index matching fluid is not used. The liquid gate provides cleaner diffraction patterns by inserting the transparencies into the gate, but the additional handling of the transparencies is inconvenient.

To eliminate or suppress artifacts in the diffraction patterns, a mask is employed when photographing the diffraction patterns. The mask is itself the photograph of the diffraction pattern of an image area (from ERTS images) with no detail such as areas of water from lakes or the ocean.

The masks have been used with very good results. Diffraction patterns photographed through them, display more clearly the spatial signatures associated with the various types of terrain, while artifacts have been substantially suppressed. The diffraction patterns of terrain types from eight ERTS images have been obtained, and are being analyzed to establish the uniqueness of spatial signatures. The terrain types include: mountains, rivers, urban areas, water, desert and cultivated land. Cultivated land from ERTS images has displayed unmistakably the familiar four frequency peak signatures we had isolated in 1971 in Apollo 9 photography of the Imperial Valley.

The final step in exploiting the spatial signatures isolated will be to write algorithms which detect the spatial signatures digitally. These will be incorporated into the existing Pattern and Terrain Classification Software System.

## 6. CONCLUSIONS

From the work done during the reporting period, we can draw certain conclusions:

1. It is possible to register digital images even from different spectral bands.
2. It is possible to develop boundaries of resources and improve the terrain recognition accuracy.
3. It is possible to merge the multispectral and terrain recognition results and expand the resource classes that can be recognized.
4. Spatial pattern signatures can be developed from the ERTS-1 images for recognizing terrain types.

5. Photointerpretation results have shown that most geographical features are recognizable in the ERTS-1 images.

7. PROGRAM FOR NEXT REPORTING PERIOD

The work planned for the remainder of the investigation involves the computer processing of ERTS images to determine the degree of success of the interpretation techniques and the resources that can be reliably recognized.

ERTS-1 images from the six test sites will be processed through the developed software.

8. RECOMMENDATIONS

High altitude (60,000 feet) aircraft photography over four test sites would be very useful to the investigation.

It is recommended that for better results the techniques developed be implemented with substantial human interaction. A completely automated approach lacks flexibility and does not seem to be workable. Since the processing is done digitally, computer driven displays to provide quick man-computer interaction are highly desirable.

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